Ballistic Missile Defense System (BMDS) Operational Test Agency (OTA)

System-Level Accreditation Challenges for the Ballistic Missile Defense System (BMDS) Models and Simulations (M&S)

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Outline

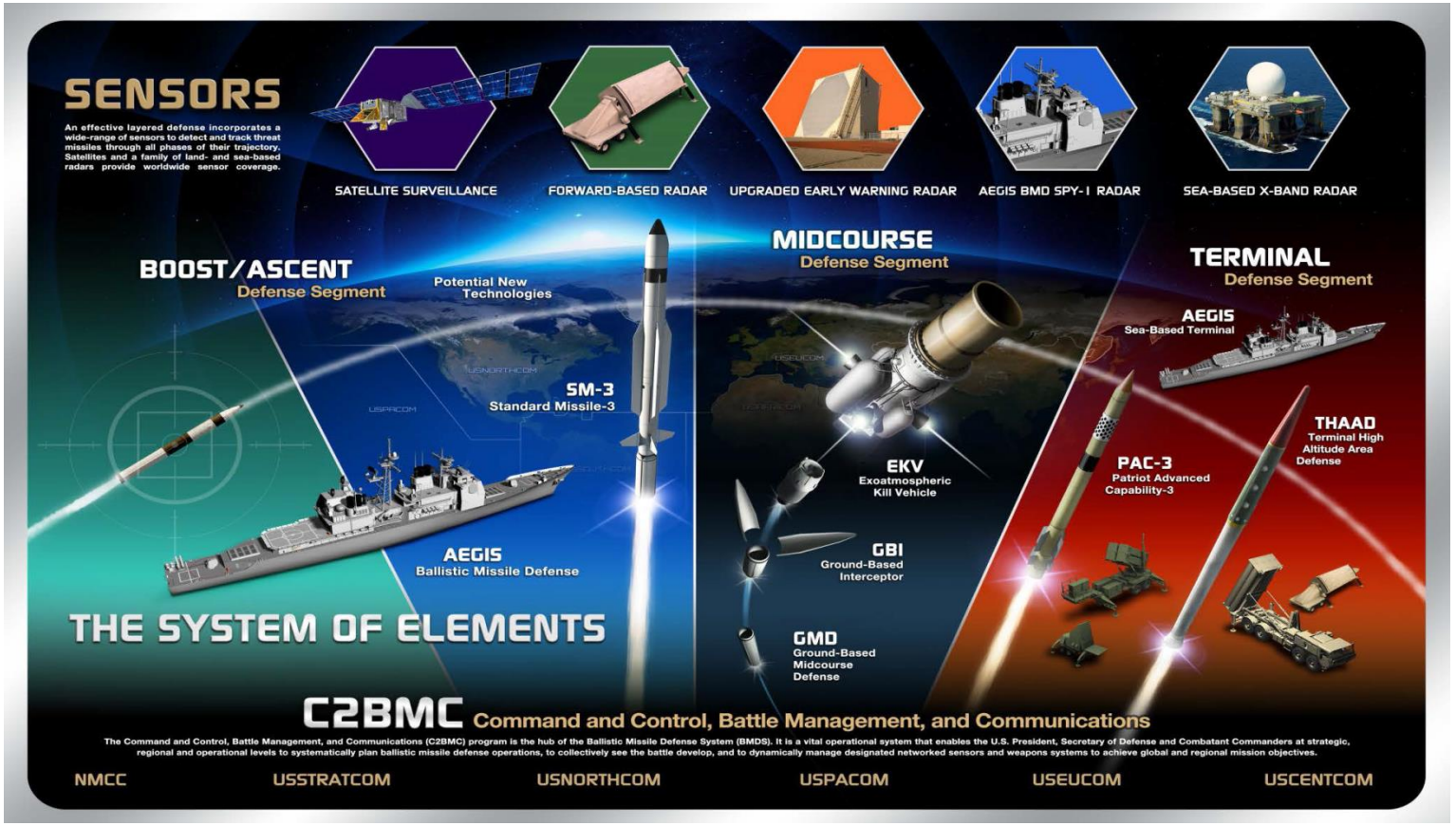
- Purpose
- BMDS – a complex federation of systems
- BMDS Testing
- Implementation and credibility of M&S
- M&S VV&A and the role of the BMDS OTA Team
- Major VV&A challenges and potential solutions
- Summary

Purpose

- **Purpose:**
  - **Describe the Modeling and Simulation (M&S) Verification, Validation and Accreditation (VV&A) process and challenges in the context of the Ballistic Missile Defense System (BMDS)**

- **Why does it matter?**
  - **The BMDS Operational Test Agency (OTA) Team's M&S accreditation and BMDS operational assessment is impacted by the challenges presented by the Verification and Validation (V&V) of the M&S used for BMDS testing**
  - **Traditional VV&A methods need to be adapted to allow for accreditation of the BDMS M&S**

BMDS – A Complex Federation of Systems



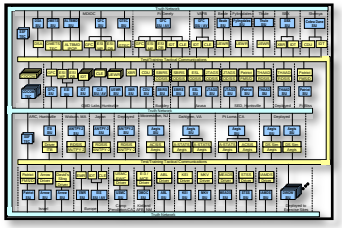
The BMDS is a collection of tactical elements, autonomously designed, developed and integrated to form a system-of-systems or federation to achieve the best possible defense against a range of potential threats.

Test Venues Desired to Support BMDS Assessment

System Level Venue

1. Live Operations

2. Flight Test
3. Integrated Lab HWIL (GTIs)



4. Distributed HWIL (GTDs)
5. Warfighter Exercises

6. Statistically Significant Simulation (SSS)
7. High-Resolution All-Digital System Simulation

System Level M&S Used

Element / Component Level Venue

8. High-Resolution All-Digital Element / Component Simulation
9. Element / Component HWIL

To assess conditions under which the BMDS is operationally effective, interoperable, suitable, and survivable, the BMDS OTA leverages data from all available credible venues

BMDS and Flight Testing

- **A Flight Test (FT) is the primary testing venue available to the BMDS that exclusively uses tactical equipment**
  - **FTs require substantial time, resources, and expertise**
  - **FTs are often limited due to various constraints, such as**
    - **Range**
    - **Environmental**
    - **Cost**
    - **Scheduling**

- **As such, comprehensive BMDS performance assessments must rely on additional sources of data to be sufficient**

Additional Testing of the BMDS

- **Challenge:**
  - **Demonstrate that this extremely complex system will perform its intended missions without being able to exercise it under its full intended operating conditions**
    - **Due to the complexity of the BMDS, it is challenging to test the system in its entirety and use only the tactical elements and components**

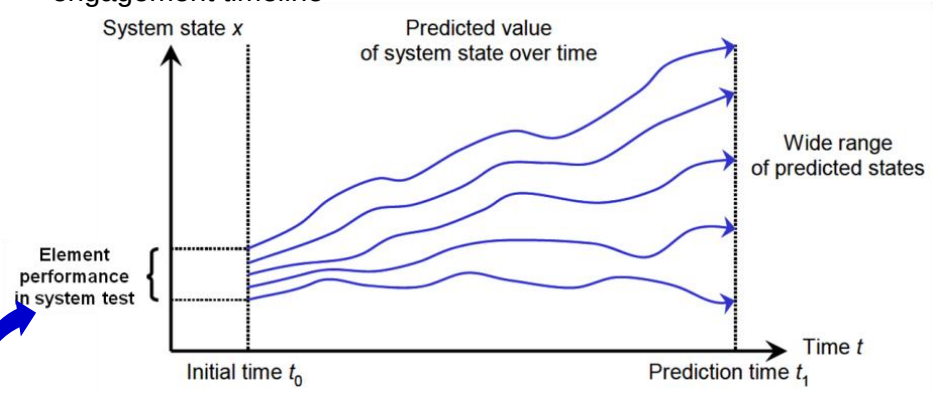
- **Solution:**
  - **Implement a strategy of capability demonstration through accredited simulations**
  - **Increase emphasis on M&S used for testing of the BMDS and for conducting the operational performance assessment**
    - **Confidence in the ability of the M&S to accurately represent the operational system performance and support fielding assessments is crucial**

Importance of M&S Credibility

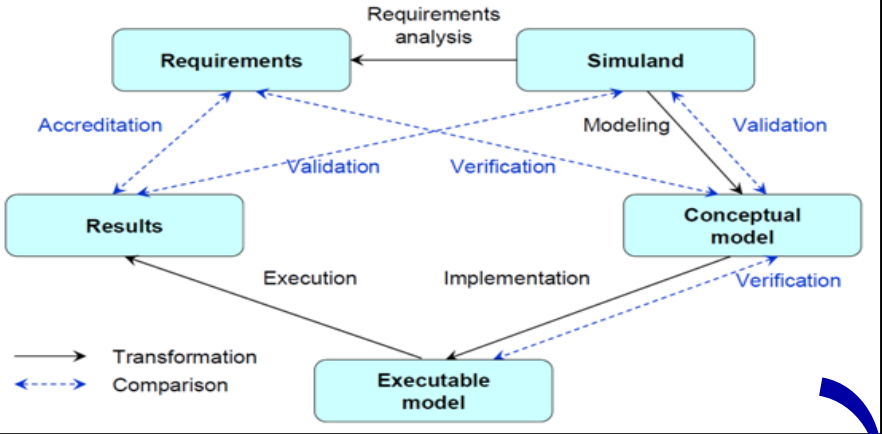
- **M&S is a critical part of the overall BMDS testing**
- **M&S needs to be relied upon to account for all element and component capabilities and limitations, and the integration of the program elements into a single federation**
- **Credible M&S provides the preferred way to:**
  - **Integrate all elements and components of the system**
  - **Solve element problems at the architecture level**
  - **Test at the architecture/integrated system level**
  - **Explore the full operational envelope of the BMDS**
  - **Look beyond current plans and programs to continue to enhance the capabilities of the BMDS**
  - **Demonstrate to the user/operator how the system is expected to perform in potential operational scenarios**
  - **Train and operate the warfighters at the system level**
  - **Justify full program spending**

BMDS – A Complex System Represented by a Complex Integration of M&S

- **The BMDS, assessed through a system of element M&S representations, is sensitive to initial conditions**
  - To explore these initial conditions and resulting performance of the BMDS, M&S accurately representing the BMDS as a single, integrated entity is required
  - Confidence in the entire BMDS representation, available only through an integrated, system-level VV&A process, provides assessment of element perturbations and the resulting effect on end-to-end BMDS performance, as small perturbations in the performance of an element have the potential to magnify across the engagement timeline



- **The number of independent interacting components is large and verification and validation of such a system requires an understanding of modeling and simulation principles in addition to breadth and depth of systems engineering processes and methods**
  - Proper measure of system M&S performance, fidelity and accuracy is only provided through full implementation of multiple functional areas and disciplines



- **There are multiple pathways by which the system can evolve**
  - Currently there are many element, M&S components, stimulus and truth services M&S, all developed individually
  - Using a digital or hardware-in-the-loop framework these M&S are integrated into a system intended to represent the BMDS in an operational environment, resulting in a complex system of systems with possibly hundreds of logic paths
  - The interrelationships between the individual M&S and the myriad of additional logic paths created would be lost without assessing the performance of the system simulation and conducting V&V of the integrated system M&S

The BMDS Operational Test Agency (OTA) Team Mission

- **The mission of the BMDS OTA is to provide an independent Operational Assessment of the BMDS**
  - **The BMDS OTA Team needs to accredit the BMDS M&S for the purpose of using the data produced by the M&S federation to conduct operational assessment of the BMDS**

- **One problematic aspect of this effort is defining what it means to perform system-level VV&A of the BMDS models and simulations given that:**
  - **There are inadequate detailed system level requirements to help clarify that role**
  - **The referent data for validation activities is limited**
  - **Identifying the significant system interactions and relevant emergent behaviors for the system performance is challenging due to the inability to test the full performance space**

VV&A Role in M&S

- **VV&A are essential steps in M&S development, systems engineering, and data output usability and credibility**
- **The purpose of VV&A is to ensure development of correct and valid simulations and to provide simulation users with sufficient information to determine if the data produced by the simulation can we used with confidence for the intended uses of the assessors**
- **Credibility depends on the simulation capabilities as needed for the specific application, and on the accuracy of a simulation necessary for the intended use**
  - **Conducting appropriate level of VV&A for the intended uses allows the organization to determine how much to rely on the simulation and the data it produces**

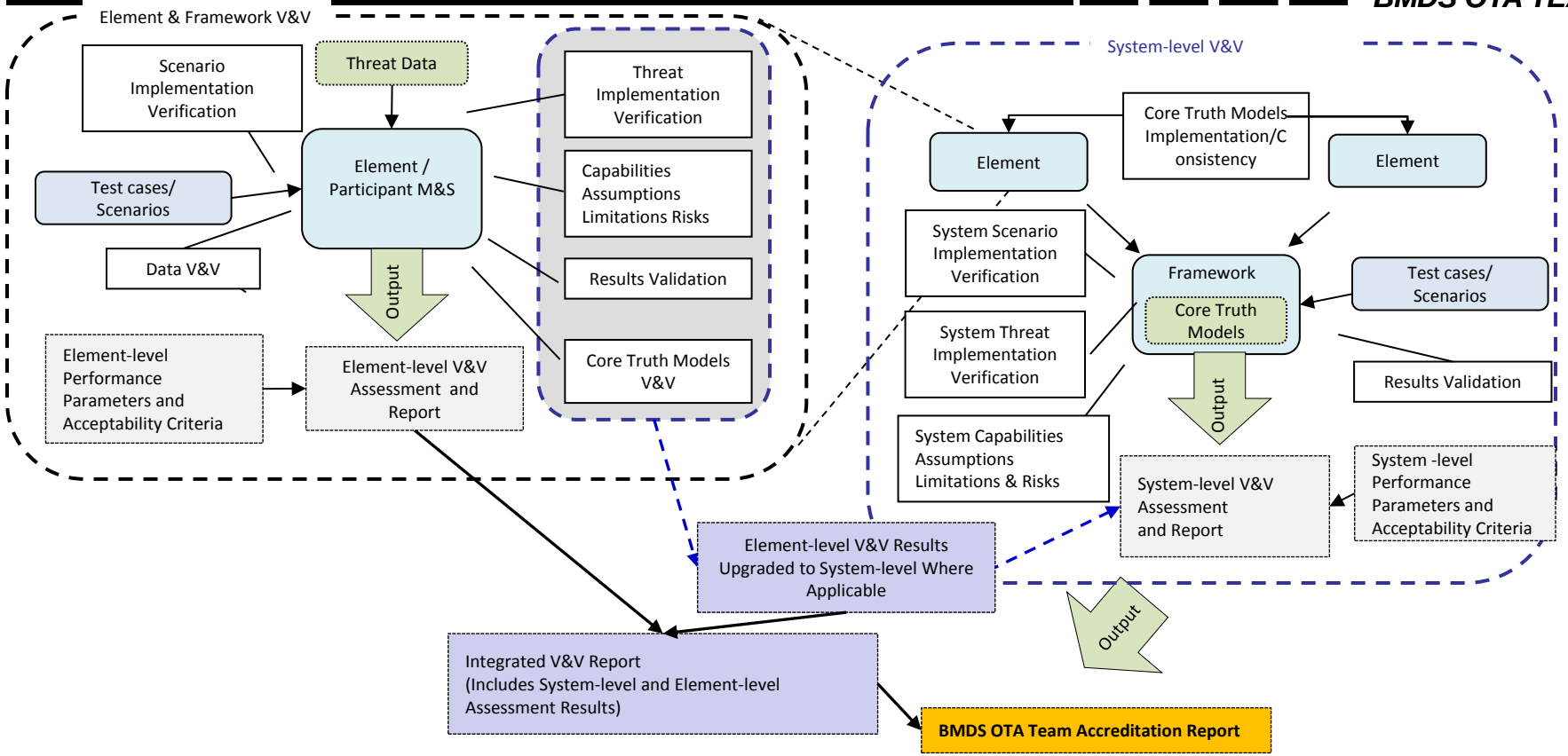
VV&A Definitions

- ***Verification***
  - **The process of determining that a model, simulation, or federation of M&S and their associated data ***accurately represents the developers' conceptual description and specifications*** (i.e., verifying the requirements)**
    - **"Did I build the thing right?"**

- ***Validation***
  - **The process of determining the degree to which a model, simulation, or federation of M&S and their associated data are an ***accurate representation of the real-world*** from the perspective of the ***intended uses*** of the M&S**
    - **"Did I build the right thing?"**

- ***Accreditation***
  - **The official certification that a model, simulation, or federation of M&S and their associated data are acceptable for us for a specific purpose**
    - **"Should this be used?"**

System-level Modeling and VV&A



System-level V&V activities allow for the assessment of the interfaces between the elements and the resulting emergent behaviors, which are not observed during element V&V efforts

Verification Challenges

- **Typically the definition of what one is intending to build is detailed in a requirements and specifications document**
  - **A set of understood expectations or requirements must exist for one to perform M&S verification**
- **In the context of BMDS M&S, the notion of verification can seem a little less clear as it might appear that the only requirement is to replicate the behavior of the system that is being simulated**
  - **Replicating the operational system is not a requirement but rather a goal for the M&S**
  - **Requirements should take the form: Under given set of conditions, the M&S will replicate given specific operational system behavior to within defined tolerance**
- **Verification at the system-level should be applied to simulation interfaces, truth models, communications models, and consistent implementation across the system**
  - **Defining system-level M&S requirements for such a complex system, as the BMDS, is a difficult task**

Validation Challenges

- **Validation processes are explicitly tied to the intended uses**
  - **Determining how close one has come to representing the real world in areas that matter for the defined intended uses**
  - **Validation at the system-level is applied to determine the extent to which element-level validation caveats and limitations impact system-level results to determine whether the system is suitable for the operational performance assessment**

- **The most challenging obstacle of the entire BMDS VV&A strategy is that of finding a way to build sufficient confidence that the M&S will faithfully represent the operational system in scenarios and conditions where there is no operational referent against which to compare or anchor the M&S**

Accreditation Challenges

- **Key to accreditation definition are the last four words, "…for a specific purpose" and these words are central to the BMDS OTA accreditation strategy**
- **Accreditation tries to answer the question "*What can the models be used for and can the data they produce be trusted?*"**
- **Complete accreditation requires evidence supporting both the verification of key M&S processes and metrics, along with validation of system behaviors and functionality for all defined intended uses**
- **A full VV&A is critical to understanding system capability and providing confidence in the M&S to represent real-world behavior of the BMDS**
- **An important step in the accreditation process is to define the intended uses and the associated performance parameters and acceptability criteria needed to assess the M&S attributes**
  - **Identifying the necessary interactions and emergent behaviors of the system, and then defining the appropriate or acceptable bounds, is yet another challenge presented in the effort to VV&A the BMDS**

New approach to VV&A

- **Due to the complexities associated with the BMDS federation and when the limited data is available as referent, it is not practical to expect and to continue to execute VV&A processes following the classical techniques**
  - **Use flight test data as the primary source of referent and limit the validation activities to performance parameter assessments**

- **The BMDS OTA Team has extended the requirement of doing V&V to allow for additional sources of data as evidence for verification and validation of the M&S**

A possible solution

- **Broad functional intended uses do not easily allow for the full accreditation of the M&S due to their generic scope and definition**
  - **E.g., it is difficult to claim that an M&S is fully accredited for performance assessment across all threats and all conditions of a particular test**

- **Can we scope the intended uses in such a way that will allow for the full accreditation of the M&S for specific assessments?**
  - **A *Mission-Oriented Intended Use (MOIU)* is an intended use that is a subset of a broad functional intended use, parallels the test scenario design requirements, and is written to describe the intended use of the M&S to assess the BMDS under very specific conditions (applicable to the current test)**

MOIU Example

- **A set of MOIUs are developed based on the test assessment objectives**
  - **These MOIUs identify how the M&S is intended to be used for BMDS assessment**
- **MOIU Example**
  - **“Use the M&S to assess the ability of the BMDS to defend the U.S. against strategic threats from country A”**
- **M&S provided V&V evidence is assessed to determine if the MOIU is supported**
  - **If so, then the M&S is accredited for the specific MOIU**
  - **If not, then the MOIU statement is further scoped or modified so that the V&V evidence supports it, or the MOIU is assigned to a future test**

MOIU Process – Step 1

- **Identify Applicability of Each Assessment Objective to M&S Components**

Example Table	Sensor-Based Sensor	Forward-Based Radar	Naval Weapons System 1	Naval Weapons 2	Battle Manager C&C	Midcourse Radar 1	Midcourse Radar 2	Interceptor	Theater Weapons System 1	Theater Weapons System 2	Threat	Environment	Communications
AO-1.1: Assess the Effectiveness of Pre-Mission Planning	x	x	x	x	x	x				x	x	x	
AO-1.2: Assess the Effectiveness of Sensor Detection	x	x	x	x		x	x		x	x	x	x	
AO-1.3: Assess the Effectiveness of Sensor Tracking		x	x	x		x	x		x	x	x	x	
AO-1.4: Assess the Effectiveness of Sensor Discrimination		x	x	x		x	x		x	x	x	x	x
AO-1.5: Assess the Effectiveness of Battle Manager Tracking and Discrimination			x	x	x				x	x	x	x	x
AO-1.6: Assess the Effectiveness of Battle Manager Engagement Planning			x	x	x				x	x	x	x	x
AO-1.7: Assess the Effectiveness of Launch Support Equipment			x	x				x	x	x		x	x
AO-1.8: Assess the Effectiveness of Interceptor Staging, Guidance, Navigation, and Control			x	x				x	x	x		x	x
AO-1.9: Assess the Effectiveness of Interceptor Acquisition, Tracking, and Discrimination			x	x				x	x	x	x	x	x
AO-1.10: Assess the Effectiveness of Intercept			x	x				x	x	x	x	x	
AO-1.11: Assess the Effectiveness of Communications	x	x	x	x	x	x	x	x	x	x		x	x
AO-1.12: Assess the Effectiveness of the System to Maintain Situational Awareness	x	x	x	x	x	x			x	x			x
AO-4.1: Assess the Interoperability of BMDS Operations	x	x	x	x	x	x	x	x	x	x			x

MOIU Process – Step 2

- **Highlight cells that are relevant to a particular MOIU**

Example Table	Sensor-Based Sensor	Forward-Based Radar	Naval Weapons System 1	Naval Weapons 2	Battle Manager C&C	Midcourse Radar 1	Midcourse Radar 2	Interceptor	Theater Weapons System 1	Theater Weapons System 2	Threat	Environment	Communications
AO-1.1: Assess the Effectiveness of Pre-Mission Planning	x	x	x	x	x	x				x	x	x	
AO-1.2: Assess the Effectiveness of Sensor Detection	x	x	x	x		x	x		x	x	x	x	
AO-1.3: Assess the Effectiveness of Sensor Tracking		x	x	x		x	x		x	x	x	x	
AO-1.4: Assess the Effectiveness of Sensor Discrimination		x	x	x		x	x		x	x	x	x	x
AO-1.5: Assess the Effectiveness of Battle Manager Tracking and Discrimination			x	x	x				x	x	x	x	x
AO-1.6: Assess the Effectiveness of Battle Manager Engagement Planning			x	x	x				x	x	x	x	x
AO-1.7: Assess the Effectiveness of Launch Support Equipment			x	x				x	x	x		x	x
AO-1.8: Assess the Effectiveness of Interceptor Staging, Guidance, Navigation, and Control			x	x				x	x	x		x	x
AO-1.9: Assess the Effectiveness of Interceptor Acquisition, Tracking, and Discrimination			x	x				x	x	x	x	x	x
AO-1.10: Assess the Effectiveness of Intercept			x	x				x	x	x	x	x	
AO-1.11: Assess the Effectiveness of Communications	x	x	x	x	x	x	x	x	x	x		x	x
AO-1.12: Assess the Effectiveness of the System to Maintain Situational Awareness	x	x	x	x	x	x			x	x			x
AO-4.1: Assess the Interoperability of BMDS Operations	x	x	x	x	x	x	x	x	x	x			x

MOIU Process – Step 3

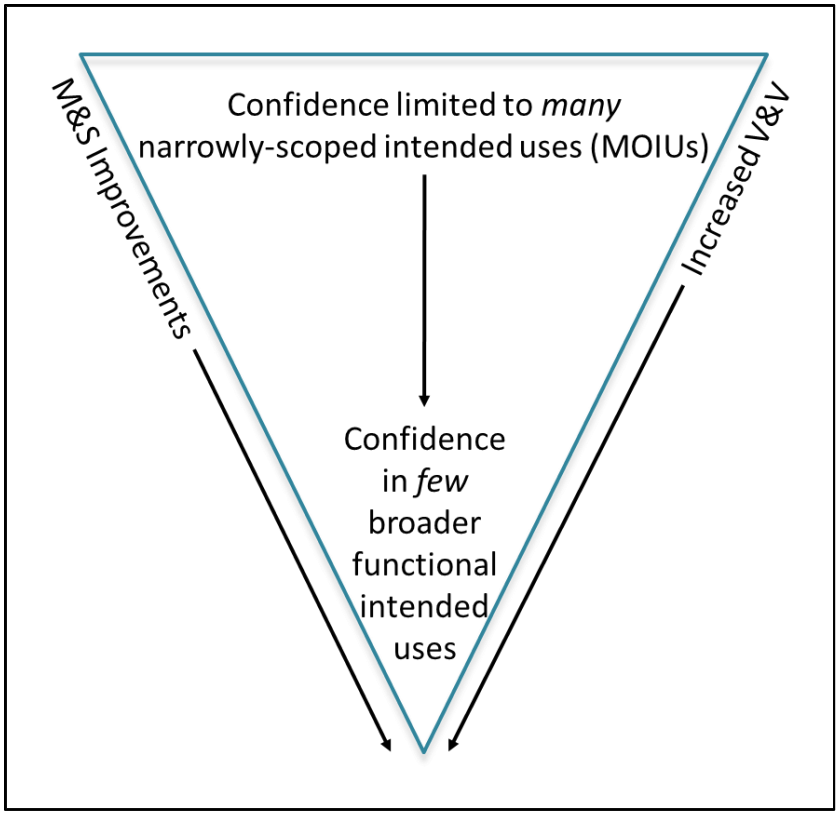
- **Assess V&V evidence for each relevant cell in the table**

Example Table	Sensor-Based Sensor	Forward-Based Radar	Naval Weapons System 1	Naval Weapons 2	Battle Manager C&C	Midcourse Radar 1	Midcourse Radar 2	Interceptor	Theater Weapons System 1	Theater Weapons System 2	Threat	Environment	Communications
AO-1.1: Assess the Effectiveness of Pre-Mission Planning	x	x	x	x	x	x				x	x	x	
AO-1.2: Assess the Effectiveness of Sensor Detection	x	x	x	x		x	x		x	x	x	x	
AO-1.3: Assess the Effectiveness of Sensor Tracking		x	x	x		x	x		x	x	x	x	
AO-1.4: Assess the Effectiveness of Sensor Discrimination		x	x	x		x	x		x	x	x	x	x
AO-1.5: Assess the Effectiveness of Battle Manager Tracking and Discrimination			x	x	x				x	x	x	x	x
AO-1.6: Assess the Effectiveness of Battle Manager Engagement Planning			x	x	x				x	x	x	x	x
AO-1.7: Assess the Effectiveness of Launch Support Equipment			x	x				x	x	x		x	x
AO-1.8: Assess the Effectiveness of Interceptor Staging, Guidance, Navigation, and Control			x	x				x	x	x		x	x
AO-1.9: Assess the Effectiveness of Interceptor Acquisition, Tracking, and Discrimination			x	x				x	x	x	x	x	x
AO-1.10: Assess the Effectiveness of Intercept			x	x				x	x	x	x	x	
AO-1.11: Assess the Effectiveness of Communications	x	x	x	x	x	x	x	x	x	x		x	x
AO-1.12: Assess the Effectiveness of the System to Maintain Situational Awareness	x	x	x	x	x	x			x	x			x
AO-4.1: Assess the Interoperability of BMDS Operations	x	x	x	x	x	x	x	x	x	x			x

MOIU Process – Step 4

- **Write the accreditation statement for the MOIU that accommodates the V&V evidence**
  - **Initial MOIU:**
    - **Use the M&S to assess the ability of the BMDS to defend the U.S. against strategic threats from country A**
  - **Modified MOIU as supported by the V&V evidence:**
    - **Use the M&S to assess the ability of the BMDS to defend the U.S. against strategic threats of type 2 from country A, from initial sensor detection up to, but not including, interceptor acquisition."**
- **Caveats:**
  - **"*of type 2*" is needed because of the M&S limitation related to sensor detection for the midcourse radar**
  - **"*from initial sensor detection up to, not including interceptor acquisition*" is needed because of the limitations in the interceptor sensor model and threat infrared signature modeling**

Scoping Intended Uses Appropriately Results in Higher-Confidence, More Specific Assessments



- **Process incrementally fills out the portions of the battle-space appropriately modeled by the M&S**
- **MOIU statements scope use of M&S to a narrow mission and context**
- **As M&S are improved and additional V&V evidence is provided, intended use statements can be broadened**
- **Approach enables M&S accreditation and supports high confidence assessments of specific capability**

Summary

- There are many challenges for the VV&A of the M&S and this requires the adaptation of classical methods with respect to VV&A activities
- In the case of the BMDS, these challenges are multiplied by the complexity of the system that the M&S is representing
- The approach suggested here does not completely solve the BMDS VV&A problem;
  - However, if implemented, these recommendations take a significant step towards the accreditation of the M&S used to simulate the BMDS
- The BMDS OTA will continue to work with the respective BMDS SMEs to further refine these ideas, and look for additional innovative ways to satisfy the VV&A requirements